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Modification of RELAX Machine and Optimization of Low-Aspect-Ratio RFP
低アスペクト比RFP装置RELAXの改造と最適化

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Poloidal flanges have been modified and saddle coils for resistive wall mode control and helical coils have been installed in Low-Aspect-Ratio Reversed Field Pinch Machine RELAX in order to realize better confinement, high beta, and high bootstrap current fraction. As a result of the modification of the poloidal flanges and some optimization of discharge conditions, dependence on compensation coils at the poloidal flanges has decreased, dependence of propagation of magnetic fluctuation on the poloidal flanges has decreased, and electron density has increased.

1. Introduction

Reversed field pinch (RFP) is a toroidal magnetic confinement system for compact, high-beta plasmas for nuclear fusion reactors.

Recent theoretical works have shown the advantages of low aspect-ratio (A) RFP. One of these advantages is that m = 1 (m is poloidal mode number) resonant surfaces are less densely spaced in the core region [1]. This leads to avoidance of overlap of magnetic islands and easier access to quasi-single-helicity (QSH) state in which single n (n is toroidal mode number) of m = 1 modes is dominant and confinement improves [2,3]. Another advantage is increase of bootstrap current. [4] has shown an equilibrium with 94% self induced current and stability β = 66% in A = 2 and reactor relevant parameters.

2. Low-Aspect-Ratio RFP Machine RELAX

The aims of low A RFP Machine "RELAX" [5-7] (major radius R_0 = 508 mm, minor radius a = 250 mm, A = R_0/a = 2) are verification of the theoretically predicted advantages of low A RFP and characterization of low A RFP. RELAX has a 4 mm thick stainless-steel (SS) toroidal wall of the vacuum vessel (resistive shell) and poloidal flanges which are 40 mm thick SS flanges to divide the vacuum vessel at two opposite toroidal angles (Fig. 1). The poloidal flanges cause asymmetry of toroidal magnetic fields and large error fields.

Because relatively high plasma pressure and high poloidal beta (β_p) is required for high bootstrap current, target parameters of RELAX are as follows; the central electron temperature T_{e0} = 300 eV, central electron density n_{e0} = 4×10^{19} m^{-3}, plasma current I_P = 100 kA, β_p ~ 24% and bootstrap current fraction ~ 20 %.

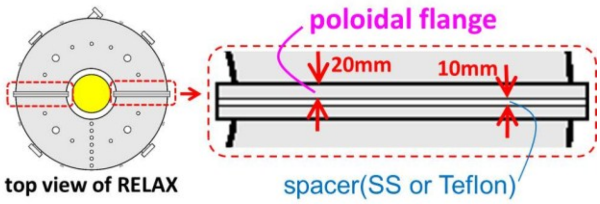

Fig.1. Poloidal flanges of RELAX

3. Modification of RELAX

In order to realize more symmetric configuration, better confinement, and as high density, temperature, β_p and bootstrap current fraction as target parameters, RELAX has been modified as follows.

(i) The poloidal flanges have been modified from ring-shaped to wheel-shaped (Fig. 2) and one of the spacers between poloidal flanges (see Fig. 1) has been changed from SS to Teflon (another spacer is Teflon both before and after modification) to increase resistance R of the wall at the poloidal flanges and improve symmetry. By these modifications, R at one toroidal angle has increased from 0.63 mΩ to 1.2 mΩ and L/R (L is inductance) has decreased from 1.7 ms to 0.92 ms.

(ii) Saddle coils for resistive wall mode control have been installed (Fig. 3). The number of sensor saddle coils is 8×16 (poloidal×toroidal) and that of actuator saddle coils is 4×16. These coils cover entire torus.

(iii) Helical coils for m = 1 mode control have been installed. One set of the helical coils is m = 1, n = -4 (innermost resonant in RELAX) and another set is $m = 1$, $n = 4$.

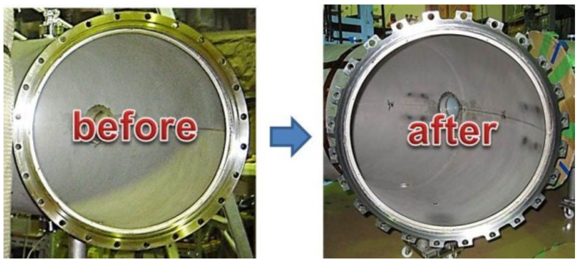

Fig.2. Photos of poloidal sections of the poloidal flanges before and after modification

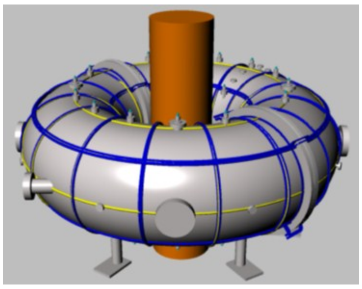

Fig.3. Saddle coils

4. Changes after Modification

Changes of plasmas after modification of poloidal flanges (except control experiment of the saddle and helical coils) and some optimization of discharge conditions are as follows.

(A) Before modification, discharges where I_P flat-top duration is relatively long and loop voltage is relatively low had been realized only with compensation toroidal magnetic field coils at the poloidal flanges as shown in Fig. 4 (a), (b). However, after modification, these discharges become possible even without the compensation coils as shown in Fig. 4 (c), (d).

(B) Before modification, in many QSH discharges of RELAX, directions of toroidal rotation of magnetic fluctuation in two half torus regions divided by the poloidal flanges are opposite to each other. After modification, probability of this phenomenon has decreased.

(C) Line averaged electron density in the low loop voltage discharges measured by interferometer ranged from 1 to 6×10^{18} m^{-3} before modification. After modification, the density has increased and ranges from 7 to 9×10^{18} m^{-3}.

From (A) and (B), it is considered that error fields due to the poloidal flanges and its effects on plasmas have decreased. (C) suggests confinement improvement and may be because of the error field correction.

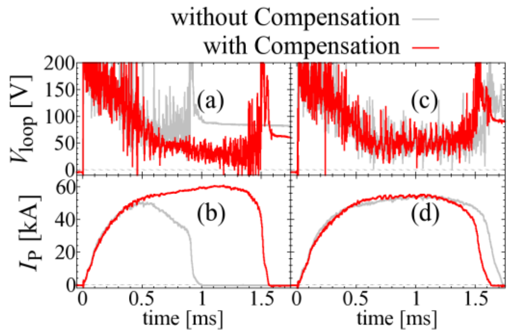

Fig.4. Time evolution of loop voltage V_{loop} and plasma current I_P with and without the compensation coils before ((a), (b)) and after ((c), (d)) modification

5. Conclusion and Future Works

As a result of modification of the poloidal flanges and some optimization, error fields due to the poloidal flanges have decreased and electron density increased.

Further optimization, resistive wall mode control by the saddle coils, and $m = 1$ perturbation by the helical coils are planed in the near future in order to improve confinement and realize high bootstrap current fraction.

Acknowledgments

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